DENSITY (UNIT WEIGHT), YIELD, AND AIR CONTENT (GRAVIMETRIC) OF CONCRETE

FOP FOR AASHTO T 121

01 Significance

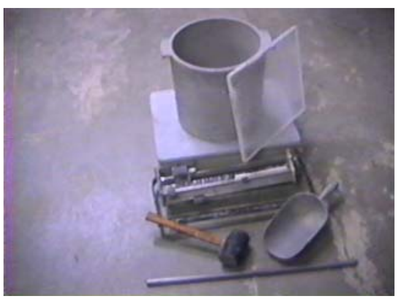
Density, formerly called “unit weight”, is a very
02 important parameter used to control the quality of
freshly mixed concrete. After a concrete mix
design has been established, a change in a
concrete’s density will indicate a change in one or
more of the other concrete performance
requirements. A lower density may indicate 1) that
03 the cement or aggregate have a lower specific
gravity than expected, 2) a higher air content, 3) a
higher water content, 4) a change in the proportions
of ingredients, and/or 5) a lower cement content.
Conversely, a higher density would indicate the
reverse of the above-mentioned characteristics.

A lower density from the established concrete mix
proportion will often indicate an “over-yield”,
meaning that the volume is greater than intended.
As a result, cement content per unit of volume is
lower than the mix design cement content. Lower
strength is to be expected as well as a reduction of
04 the other desirable qualities. If the reduction in
density is due to an increase in air content, the
concrete may be more durable in its resistance to
cycles of freezing and thawing, but strength,
abrasion resistance, and resistance to chemical
attack, shrinkage, and cracking will be adversely
affected. A change in density could also affect the
pumpability, placeability, and finishability. The
density test can also be used to determine the air
content of concrete, as long as the theoretical
density of the concrete computed on an air-free
basis is known.

Scope

This procedure covers the determination of density, or unit weight, of freshly mixed concrete in accordance with AASHTO T 121. It also provides formulas for calculating the volume of concrete produced from a mixture of known quantities of component materials, and provides a method for calculating cement content & cementitious material content – the mass of cement or cementitious material per unit volume of concrete. A procedure for calculating water/cement ratio is also covered.

05 ## Apparatus



Apparatus

- Measure: May be the bowl portion of the air meter used for determining air content under the FOP for AASHTO T 152. Otherwise, it shall be
06 a metal cylindrical container meeting the requirements of AASHTO T 121. The capacity and dimensions of the measure shall conform to those specified in Table 1.
- Balance or scale: Accurate to 0.3 percent of the test load at any point within the range of use.
- Tamping Rod: 16 mm (5/8 in.) diameter and approximately 600 mm (24 in.) long, having a hemispherical tip. (Hemispherical means “half a sphere”; the tip is rounded like half of a ball.)
- Vibrator: 7000 vibrations per minute, 19 to 38 mm (3/4 to 1 1/2 in.) in diameter, and the length of the shaft shall be at least 610 mm (24 in).
- Scoop
- Strike-off Plate: A flat rectangular metal plate at least 6 mm (1/4 in.) thick or a glass or acrylic plate at least 12 mm (1/2 in.) thick, with a length and width at least 50 mm (2 in.) greater than the diameter of the measure with which it is to be used. The edges of the plate shall be straight and smooth within tolerance of 1.5 mm (1/16 in.).
- Mallet: With a rubber or rawhide head having a mass of 0.57 ±0.23 kg (1.25 ±0.5 lb) for use with measures of 0.014 m^3 (1/2 ft^3) or less, or having a mass of 1.02 ±0.23 kg (2.25 ±0.5 lb) for use with measures of 0.028 m^3 (1 ft^3).

Table 1
Dimensions of Measures

Capacity m3 (ft3)	Inside Diameter mm (in.)	Inside Height mm (in.)	Minimum Thicknesses mm(in.)		Nominal Maximum Size of Coarse Aggregate ** mm (in.)
			Bottom	Wall	
0.0071	203 ±2.54	213 ±2.54	5.1	3.0	25
(1/4)	(8.0 ±0.1)	(8.4 ±0.1)	(0.20)	(0.12)	(1)
0.0142	254 ±2.54	279 ±2.54	5.1	3.0	50
(1/2)	(10.0 ±0.1)	(11.0 ±0.1)	(0.20)	(0.12)	(2)
0.0283	356 ±2.54	284 ±2.54	5.1	3.0	76
(1)	(14.0 ±0.1)	(11.2 ±0.1)	(0.20)	(0.12)	(3)

* ***Note:*** Measure may be the base of the air meter used in the FOP for AASHTO T 152.

**Nominal Maximum size: One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.

Calibration of Measure

07 1. Determine the mass of the dry measure and strike-off plate.
2. Fill the measure with water at a temperature between 16°C and 29°C (60°F and 85°F) and cover with the strike-off plate in such a way as to eliminate bubbles and excess water.
3. Wipe the outside of the measure and cover plate dry, being careful not to lose any water from the measure.
4. Determine the mass of the measure, strike-off plate, and water in the measure.
5. Determine the mass of the water in the measure by subtracting the mass in Step 1 from the mass in Step 4.
6. Measure the temperature of the water and determine its density from Table 2, interpolating as necessary.
7. Calculate the volume of the measure, V_m, by dividing the mass of the water in the measure by the density of the water at the measured temperature, from Table 2.

Example: at 23°C (73.4°F)

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09 $$V_m = \frac{7.062 \text{ kg}}{997.54 \text{ kg/m}^3} = 0.007079 \text{ m}^3$$

$$V_m = \frac{15.53\,lb}{62.274\,lb/\text{ft}^3} = 0.2494 \text{ ft}^3$$

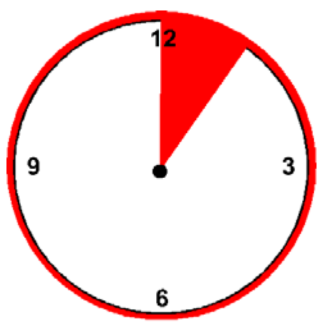
Table 2
Unit Mass of Water
15°C to 30°C

°C	(°F)	kg/m³	(lb/ft³)	°C	(°F)	kg/m³	(lb/ft³)
15	(59.0)	999.10	(62.372)	23	(73.4)	997.54	(62.274)
15.6	(60.0)	999.01	(62.366)	23.9	(75.0)	997.32	(62.261)
16	(60.8)	998.94	(62.361)	24	(75.2)	997.29	(62.259)
17	(62.6)	998.77	(62.350)	25	(77.0)	997.03	(62.243)
18	(64.4)	998.60	(62.340)	26	(78.8)	996.77	(62.227)
18.3	(65.0)	998.54	(62.336)	26.7	(80.0)	996.59	(62.216)
19	(66.2)	998.40	(62.328)	27	(80.6)	996.50	(62.209)
20	(68.0)	998.20	(62.315)	28	(82.4)	996.23	(62.192)
21	(69.8)	997.99	(62.302)	29	(84.2)	995.95	(62.175)
21.1	(70.0)	997.97	(62.301)	29.4	(85.0)	995.83	(62.166)
22	(71.6)	997.77	(62.288)	30	(86.0)	995.65	(62.156)

Procedure Selection

10 There are two methods of consolidating the concrete – rodding and vibration. If the slump is greater than 75 mm (3 in.), consolidation is by rodding. When the slump is 25 to 75 mm (1 to 3 in.), internal vibration or rodding can be used to consolidate the sample, but the method used must be that required by the agency in order to obtain consistent, comparable results. For slumps less than 25 mm (1 in.), consolidate the sample by internal vibration.

Procedure - Rodding



5 Minutes!

11 1. Obtain the sample in accordance with the FOP for WAQTC TM 2. Testing may be performed in conjunction with the FOP for AASHTO
12 T 152. When doing so, this FOP should be performed prior to the FOP for AASHTO T 152.

Note 1: If the two tests are being performed using the same sample, this test shall begin within five minutes of obtaining the sample.

2. Determine the mass of the dry empty measure.
3. Dampen the inside of the measure.
4. Fill the measure approximately 1/3 full with concrete.

Consolidation

5. Consolidate the layer with 25 strokes of the tamping rod, using the rounded end. Distribute the strokes evenly over the entire cross section of the concrete. Rod throughout its depth
13 without hitting the bottom too hard.
6. Tap the sides of the measure smartly 10 to 15 times with the mallet to close voids and release trapped air.
7. Add the second layer, filling the measure about 2/3 full.

14 8. Consolidate this layer with 25 strokes of the tamping rod, penetrating about 25 mm (1 in.) into the bottom layer.

9. Tap the sides of the measure smartly 10 to 15 times with the mallet.

10. Add the final layer, slightly overfilling the
15 measure.

11. Consolidate this layer with 25 strokes of the tamping rod, penetrating about 25 mm (1 in.) into the second layer.

12. Tap the sides of the measure smartly 10 to 15 times with the mallet.

Note 2: The measure should be slightly over full, about 3 mm (1/8 in.) above the rim. If there is a great excess of concrete, remove a portion with the scoop. If the measure is under full, add a small quantity. This adjustment may be done only after consolidating the final layer and before striking off the surface of the concrete.

13. Strike off by pressing the strike-off plate flat
16 against the top surface covering approximately 2/3 of the measure. Withdraw the strike-off plate with a sawing motion to finish the 2/3 originally covered. Cover the original 2/3 again with the plate; finishing the remaining 1/3 with a sawing motion (do not lift the plate, continue
17 the sawing motion until the plate has cleared the surface of the measure). Final finishing may be accomplished with several strokes with the inclined edge of the strike-off plate. The
18 surface should be smooth and free of voids.

19 14. Clean off all excess concrete from the exterior of the measure including the rim.

15. Determine and record the mass of the measure and the concrete to the nearest 0.3%.

16. If the air content of the concrete is to be determined, proceed to Rodding Procedure Step 13 of the FOP for AASHTO T 152.

20 Procedure - Internal Vibration

1. Perform Steps 1 through 3 of the rodding procedure.
2. Fill the measure approximately half full.
3. Insert the vibrator at four different points in each layer when a 0.0283 m^3 (1 ft^3) measure is used, and three different points in each layer when a 0.0142 m^3 (1/2 ft^3), or smaller, measure is used. Do not let the vibrator touch the bottom or sides of the measure.

Note 3: Remove the vibrator slowly, so that no air pockets are left in the material.

Note 4: Continue vibration only long enough to achieve proper consolidation of the concrete. Over vibration may cause segregation and loss of appreciable quantities of intentionally entrained air.

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4. Fill the measure a bit over full.
5. Insert the vibrator as in Step 3. Do not let the vibrator touch the sides of the measure, and penetrate the first layer approximately 25 mm (1 in.).
6. Return to Step 13 of the rodding procedure and continue.

Calculations

- **Density –** Calculate the net mass, M_m, of the concrete in the measure by subtracting the mass of the measure from the gross mass of the measure plus the concrete. Calculate the density, W, by dividing the net mass, M_m, by the volume, V_m, of the measure as shown below.

$$W = \frac{M_m}{V_m} \quad \text{Example: } W = \frac{16.920\,\text{kg}}{0.007079\,\text{m}^3} = 2390\,\text{kg/m}^3 \quad W = \frac{36.06\,lb}{0.2494\,ft^3} = 144.6\,lb/\text{ft}^3$$

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- **Yield –** Calculate the yield, Y, or volume of concrete produced per batch, by dividing the total mass of the batch, W_1, by the density , W, of the concrete as shown below.

$$Y = \frac{W_1}{W} \quad \text{Example: } Y = \frac{2436\,\text{kg}}{2390\,\text{kg/m}^3} = 1.02\,\text{m}^3 \quad Y = \frac{3978\,lb}{(27)\,(144.6\,\text{lb}/\,ft^3)} = 1.02\,yd^3$$

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Note 5: The total mass, W_1, includes the masses of the cement, water, and aggregates in the concrete.

- **Cement Content –** Calculate the actual cement content, N, by dividing the mass of the cement, N_t, by the yield, Y, as shown below.

  Note 6: Specifications may require Portland cement content and cementitious materials content 24, 25

$$N = \frac{N_t}{Y} \quad \text{Example: } N = \frac{261\,\text{kg}}{1.02\,\text{m}^3} = 256\,\text{kg/m}^3 \qquad N = \frac{602\,\text{lb}}{1.02\,yd^3} = 590\,lb/\text{yd}^3$$

- **Water Content –** Calculate the mass of water in a batch of concrete by summing the:
  - water added at batch plant
  - water added in transit
  - water added at jobsite
  - free water on coarse aggregate
  - free water on fine aggregate
  - liquid admixtures (if the agency requires this to be included).

This information is obtained from concrete batch tickets collected from the driver. Use the following conversion factors.

To Convert From	To	Multiply By
Liters, L	Kilograms, kg	1.0
Gallons, gal	Kilograms, kg	3.785
Gallons, gal	Pounds, lb	8.34
Milliliters, mL	Kilograms, kg	0.001
Ounces, oz	Milliliters, mL	28.4
Ounces, oz	Kilograms, kg	0.0284
Ounces, oz	Pounds, lb	0.0625
Pounds, lb	Kilograms, kg	0.4536

Calculate the mass of free water on aggregate as follows.

$$Free\ Water\ \ Mass\ = Total\ Aggregate\ Mass\ - \frac{Total\ \ Aggregate\ \ Mass}{1+(Free\ Water\ \ Percentage\ /100)}$$

Example:

Total Aggregate Mass = 3540 kg (7804 lb)

Free Water Percentage = 1.7 *

* To determine Free Water percentage:

Total moisture content of the aggregates – absorbed moisture = Free Water

$$Free\ Water\ \ Mass\ = 3540\,kg\ - \frac{3540\,kg}{1+(1.7/100)} = 59\,kg \qquad 7804\,lb - \frac{7804\,lb}{1+(1.7/100)} = 130\,lb$$

Example for actual water content:

Water added at batch plant =	300 L		79 gal	
Water added in transit =	0 L			
Water added at jobsite =	40 L		11 gal	
	340 L	=340 kg	90 gal =	751 lbs

Coarse aggregate: 3540 kg (7804 lb) @ 1.7% free water
Fine aggregate: 2490 kg (5489 lb) @ 5.9% free water

CA free water = $3540\ \text{kg} - \dfrac{3540\ \text{kg}}{1 + (1.7/100)} = 59\ \text{kg}$ $\quad 7804\,lb - \dfrac{7804\,lb}{1 + (1.7/100)} = 130\ \text{lbs}$

FA free water = $2490\ \text{kg} - \dfrac{2490\ \text{kg}}{1 + (5.9/100)} = \underline{139\ \text{kg}}$ $\quad 5489\,lb - \dfrac{5489\,lb}{1 + (5.9/100)} = \underline{306\ \text{lbs}}$

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Mass of water in batch = 538 kg 1187 lbs

- **Water/Cement Ratio –** Calculate the water/cement ratio by dividing the mass of water in a batch of concrete by the mass cementitious material in the batch. The masses of the cementitious materials are obtained from concrete batch tickets collected from the driver.

  Example:

Cement:	950 kg	2094 lbs
Fly Ash:	180 kg	397 lbs
Water:	538 kg (from previous example)	1187 lbs

$$\text{W/C} = \frac{538\,\text{kg}}{(950+180\,\text{kg})} = 0.476\text{, say } 0.48 \qquad \text{W/C} = \frac{1187\,lb}{(2094+397\,lb)} = 0.48$$

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Report

Results shall be reported on standard forms approved for use by the agency and should include the following:

- Density (unit weight) to 1 kg/m^3 (0.1 lb/ft^3).
- Yield to 0.01m^3 (0.01 yd^3)
- Cement content to 1 kg/m^3 (1 lb/yd^3)
- Cementitious material to 1 kg/m^3 (1 lb/yd^3)
- Water/Cement ratio to 0.01

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Tips!

- Start within 5 minutes of obtaining sample if done along with AASHTO T 152.
- Consolidation technique depends on slump. Rodding and/or vibration may be appropriate for different slumps.
- Use a calibrated measure.

REVIEW QUESTIONS

1. What is the required shape of the tamping end of the rod?

2. What is the minimum thickness of a metal strike off plate?

3. What is the minimum thickness for a glass or acrylic strike-off plate?

4. What is the specified mass of the mallet used on measures having a volume of 0.028 m^3 (1 ft^3)?

5. Air meter bases used for this test must conform to what test method?

6. If, after consolidation of the final layer, the concrete level is 12.5 mm (1/2 in) above the top of the measure, what should be done?

7. After completing the strike-off procedure, what must be done before determining the mass of the measure and sample?

PERFORMANCE EXAM CHECKLIST

DENSITY (UNIT WEIGHT), YIELD, AND AIR CONTENT (GRAVIMETRIC) OF CONCRETE
FOP FOR AASHTO T 121

Participant Name ______________________________ Exam Date ______________

Record the symbols "P" for passing or "F" for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. Mass and volume of empty measure determined?	_____	_____
2. Dampened measure filled in three equal layers, slightly overfilling the last layer?	_____	_____
3. Each layer rodded throughout its depth 25 times with hemispherical end of rod, uniformly distributing strokes?	_____	_____
4. Bottom layer rodded throughout its depth, without forcibly striking the bottom of the measure?	_____	_____
5. Middle and top layers rodded, each throughout their depths and penetrating the previous layer by approximately 25 mm (1 in.) into the underlying layer?	_____	_____
6. Sides of the measure tapped 10 to 15 times with the mallet after rodding each layer?	_____	_____
7. Any excess concrete removed using a trowel or a scoop, or small quantity of concrete added to correct a deficiency, after consolidation of final layer?	_____	_____
8. Strike-off plate placed flat on the measure covering approximately 2/3 of the surface then sawing action used to remove the strike-off plate across the previously covered surface?	_____	_____
9. Strike-off plate placed flat on the measure covering approximately 2/3 of the surface then sawing action used to remove the plate across the entire measure surface.	_____	_____
10. Strike off completed using the inclined edge of the plate creating a smooth surface?	_____	_____
11. All excess concrete cleaned off and mass of full measure determined?	_____	_____
12. Net mass calculated?	_____	_____

OVER

Procedure Element	**Trial 1**	**Trial 2**
13. Density calculated?	_____	_____

Comments: First attempt: Pass ☐ Fail ☐ Second attempt: Pass ☐ Fail ☐

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Examiner Signature _______________________________WAQTC #:_______________